Implications of the ATLAS and CMS searches in the channel pp→Higgs→$\tau^+\tau^-$ for the MSSM and SM Higgs bosons

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Abstract

We discuss the implications of the recent constraints on the Higgs sector of the Minimal Supersymmetric extension of the Standard Model obtained by the ATLAS and CMS collaborations at the lHC with $\sqrt{s} = 7$ TeV and 36 pb^{-1} of data. The main production and detection channel that is relevant in these analyses is the gluon–gluon and bottom quark fusion mechanisms leading to neutral Higgs bosons which subsequently decay into tau lepton pairs, $gg, b\bar{b} \to \text{Higgs} \to \tau^+\tau^-$. In this note, we show that: i) the exclusion limits are in fact more general than indicated by the ATLAS and CMS analyses and are essentially independent of the scenario for the supersymmetric particle spectrum; ii) when the exclusion limits are applied to the lowest theory prediction for the Higgs production cross section times branching ratio, when all theoretical uncertainties are taken into account, the bounds are somewhat less stringent; iii) the exclusion limits from the $pp \to \text{Higgs} \to \tau^+\tau^-$ process are so strong that only a modest improvement would be possible when other MSSM Higgs detection channels are considered, even with femtobarn level accumulated data. Finally and most important, we point out that the prospects for the search for the Standard Model Higgs boson in the inclusive $gg \to H \to \tau^+\tau^-$ channel, that is not currently considered by the ATLAS and CMS collaborations, turn out to be very promising and with a few inverse femtobarn data it might provide a convincing discovery signal in the difficult 115–135 GeV mass range for the standard Higgs boson.

1. Introduction

The first analyses of supersymmetric Higgs production at the early stage of the large Hadron Collider (lHC) have been recently released by the ATLAS and CMS collaborations [1, 2]. Searches for the neutral Higgs bosons of the Minimal Supersymmetric Standard Model (MSSM), in which the Higgs sector is extended to contain five scalar particles, two CP–even h, H bosons, a CP–odd or pseudoscalar A boson and two charged $H^{\pm}$ particles [3], have been performed at a center of mass energy of $\sqrt{s} = 7$ TeV and with 36 pb^{-1} of data in the inclusive channel $pp \to \tau^+\tau^-$. The obtained results are rather impressive: in the absence of an additional Higgs contribution on top of the continuum background, very stringent limits on the MSSM Higgs sector, beyond those available from the LEP [4] and Tevatron [5] experiments, have been derived. In particular, values $\tan\beta \gtrsim 25$–40 for the ratio of vacuum expectation values of the two Higgs fields (that is expected to lie in the range $1 \lesssim \tan\beta \lesssim 60$) have been excluded for pseudoscalar Higgs mass values in the range between 100 and 200 GeV.

In the MSSM, only two parameters are needed to describe the Higgs sector at tree–level: $\tan\beta$ and the pseudoscalar mass M_A. At high $\tan\beta$ values, $\tan\beta \gtrsim 10$, one of the neutral CP–even states has almost exactly the properties of the Standard Model (SM) Higgs particle: its couplings to fermions and gauge bosons are the same, but its mass is restricted to values $M_h^{\max} \approx 110$–135 GeV depending on the radiative corrections that enter the MSSM Higgs sector [3,6]. The other CP–even state (H in the decoupling regime $M_A \gtrsim M_h^{\max}$ and h in the antidecoupling regime $M_A \lesssim M_h^{\max}$) and the CP–odd state, that we will denote collectively by $\Phi = A, H(h)$, are then almost degenerate in mass and have the same very strongly enhanced couplings to bottom quarks and τ–leptons ($\propto \tan\beta$) and suppressed couplings to top quarks and gauge bosons. This leads to a rather simple phenomenology for these states: the Φ bosons decay almost exclusively into $b\bar{b}$ and $\tau^+\tau^-$ pairs and, at hadron colliders, these states are primarily produced in the gluon–gluon fusion mechanism, $gg \to \Phi$, which dominantly proceeds through b–quark triangular loops [7,8] and bottom–quark fusion, $b\bar{b} \to \Phi$ [9,10], in which the bottom quarks are directly taken from the protons in a five active flavor scheme[1].

Recently, the processes $pp \to gg + b\bar{b} \to \Phi \to \tau^+\tau^-$ have been analyzed for the lHC [12]: the production cross sections and the decay branching fractions have been updated (for the cross section part, see also Ref. [13]) and the associated theoretical uncertainties, which turned out to be quite large, have been discussed in detail. Relying on this analysis, we will show in the present note that:

i) The ATLAS and CMS exclusion limits in the $[M_A, \tan\beta]$ parameter space, which have been presented in the so–called $M_h^{\max}$ maximal mixing benchmark scenario that maximizes the h boson mass [14], are in fact almost model independent as the supersymmetric particle spectrum enters mainly through a radiative correction to the Higgs–$b\bar{b}$ Yukawa coupling that essentially cancels out in the production cross section times decay branching ratio.

ii) If the ATLAS and CMS limits are applied to the minimal predicted $pp \to \Phi \to \tau^+\tau^-$ rate when the theoretical uncertainties are properly taken into account, the excluded range in the $[M_A, \tan\beta]$ plane is slightly smaller than indicated: only values $\tan\beta \gtrsim 30$–50 are excluded in the mass range 100 GeV $\lesssim M_A \lesssim 200$ GeV.

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[1]This process is similar to the $pp \to b\bar{b}\Phi$ channel [11] when no b–quarks are detected in the final state.

iii) These ATLAS and CMS exclusion limits will be significantly improved with additional data and, for the luminosity of 1–3 fb^{-1} expected at the end of the $\sqrt{s} = 7$ lHC run, they will be so strong that all other neutral and charged MSSM Higgs search channels will add only a modest improvement and will not be relevant anymore for discovery.

Finally, and most important, we point out that using the present analyses but with a few inverse femtobarn accumulated data, the search for the SM Higgs particle in the process $gg \to H \to \tau^+\tau^-$, which is not currently considered by the ATLAS and CMS collaborations, might prove to be very promising and a Higgs discovery would be possible in the otherwise rather difficult mass range $115 \text{ GeV} \lesssim M_H \lesssim 135 \text{ GeV}$ at the end of the early LHC run.

2. pp$\to\Phi\to\tau^+\tau^-$ production rates and model independence

The evaluation of the cross sections in the $gg \to \Phi$ and $b\bar{b} \to \Phi$ production processes at the lHC has been discussed in detail in Ref. [12] and we will only summarize here the main lines. Concentrating on the pseudoscalar A boson case at high $\tan\beta$ values, $\sigma(gg \to A)$ which is known up to next-to-leading order (NLO) only [8] is calculated using the program HIGLU [15] with central values for the renormalization and factorization scales[2], $\mu_R = \mu_F = \mu_0 = \frac{1}{2}M_A$; only the very strongly enhanced loop contribution of the bottom quark is taken into account. For the $b\bar{b} \to A$ process, known up to next-to-next-to-leading order (NNLO) [10], we use the program bbh@nnlo [16] with a central scale $\mu_R = \mu_F = \mu_0 = \frac{1}{4}M_A$. In both cases, the $\overline{\text{MS}}$ scheme for the renormalization of the b–quark mass is adopted[3]. The resulting partonic cross sections are then folded with the latest MSTW sets of PDFs [17], consistently at the respective perturbative orders. The cross sections are then multiplied by the $A \to \tau^+\tau^-$ decay branching fraction that we evaluate using the program HDECAY [18] in which all (suppressed) channels except for $A \to b\bar{b}$ and $\tau^+\tau^-$ are ignored, leading to a value $\text{BR}(A \to \tau^+\tau^-) = m_\tau^2/[3\overline{m}_b^2(M_A) + m_\tau^2] \approx 10\%$.

In both production and decay processes, we assume the $b\bar{b}A$ coupling to be SM–like, $\lambda_{Abb} = m_b/v$. To obtain the true cross sections, one has to rescale the obtained numbers by a factor $\tan^2\beta$. In addition, to obtain the cross section for both the A and $H(h)$ bosons, an additional factor of two has to be included. In most cases, this turns out to be a very good approximation[4] for the following reasons:

i) As a consequence of chiral symmetry for $M_\Phi \gg \overline{m}_b$ and because the Higgs masses and couplings are very similar, the production and decay amplitudes are the same for A and $H(h)$. The only exception to our simple rule is at masses $M_A \approx M_h^{\max}$. In this case, we are not anymore in the decoupling or antidecoupling regimes, but in the so–called intense coupling regime [19] in which the three neutral Higgs bosons have comparable masses and similarly enhanced couplings to b–quarks. As the squares of the CP–even Higgs couplings add to the square of the CP–odd Higgs coupling, and since $M_H \approx M_h \approx M_A$, our results are recovered provided that the cross section times branching ratios for the three h, H, A particles are added.

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[2]Our central scale is the same as the one adopted in the SM Higgs case and is thus different from that used in Ref. [13] where $\mu_0 = M_H$ has been chosen; we thus obtain a $gg \to A$ cross section that is $\approx 10\%$ larger.

[3]However, while the value $\overline{m}_b(\overline{m}_b)$ is used in the gg process, $\overline{m}_b(\mu_R)$ is adopted in the $b\bar{b}$ channel.

[4]This approximation is very useful in practice as it prevents the need of large grids to tackle numerically every MSSM scenario as well as CPU time consuming scans of the supersymmetric parameter space.

ii) As the pseudoscalar A boson does not couple to squarks of the same flavor ($A\tilde{q}_i\tilde{q}_i$ couplings are forbidden by CP–invariance), there is no superparticle contribution in the $gg \to A$ process at leading order and higher order corrections are suppressed. In the CP–even Higgs case, there are additional superparticle contributions to $gg \to H(h)$ originating from (mainly stop and sbottom) squark loops. However, these contributions are damped by the squark mass squared and are not similarly enhanced by $m_b \tan\beta$ factors; they thus remain small so that they can be safely neglected in most cases.

iii) The only relevant effect of the supersymmetric particles appears through the one–loop vertex correction Δ_b [20] to the $\Phi b\bar{b}$ coupling which can be significant as it grows with $\tan\beta$. However, in the case of $pp \to \Phi \to \tau^+\tau^-$, this correction almost entirely cancels out in the cross section times branching ratios and the remaining part is so small that it has no practical impact whatever benchmark scenario is considered. Indeed, the Δ_b correction induces a shift

$$\sigma \times \mathrm{BR} \to \frac{\sigma}{(1+\Delta_b)^2} \times \frac{\Gamma(\Phi \to \tau\tau)}{(1+\Delta_b)^{-2}\Gamma(\Phi \to b\bar{b}) + \Gamma(\Phi \to \tau\tau)} \approx \sigma \times \mathrm{BR} \times (1 - \frac{1}{5}\Delta_b) \qquad (1)$$

assuming $\mathrm{BR}(\Phi \to \tau^+\tau^-) \approx 10\%$. Thus, unless the Δ_b correction is extremely large, it will lead to only a few percent correction at most to the cross section times decay branching, which is negligible in view of the much larger QCD uncertainties as will be discussed later.
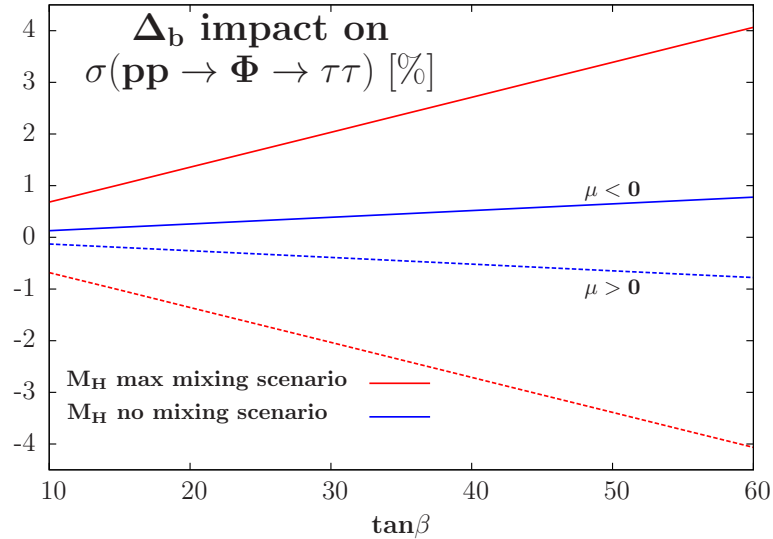

Figure 1: The impact (in %) of the Δ_b supersymmetric radiative correction on the cross section times branching ratio $\sigma[pp \to A + H(h)] \times \mathrm{BR}[A/H(h) \to \tau^+\tau^-]$ as a function if $\tan\beta$ in two of the benchmark scenarios of Ref. [14] for both signs of μ.

This feature is illustrated in Fig. 1 where, using the program FeynHiggs [21] to evaluate the Δ_b correction, we display for a fixed value of M_A and as a function of $\tan\beta$, the impact of the Δ_b correction on $\sigma(gg + b\bar{b} \to \Phi) \times \mathrm{BR}(\Phi \to \tau\tau)$. This is done in two benchmark scenarios for the CP–conserving MSSM proposed in Ref. [14]: the maximal M_h^{max} mixing and the M_h^{min} no–mixing Higgs scenarios[5], with the two possible signs of the higgsino parameter μ.

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[5]The gluophobic scenario is now ruled out as it leads to light gluinos $m_{\tilde{g}} = 500$ GeV) and squarks ($m_{\tilde{q}} \approx 350$

As can be seen, in both cases the quality of our approximation for the $pp \to \Phi \to \tau^+ \tau^-$ cross section is always very good, the difference with the exact result including the Δ_b correction being less than 2% for $\tan\beta \lesssim 30$ (and $\lesssim 4\%$ for $\tan\beta \lesssim 60$), which is negligible in view of the large QCD uncertainties that affect the cross section.

Thus, our approximation is very good and the exclusion limit derived from the ATLAS and CMS analyses depend very little on the supersymmetric model under consideration. In fact, they also hold in a general two–Higgs doublet model in which two Higgs particles have the same mass and the same enhanced couplings to isospin down–type fermions.

3. Impact of the theoretical uncertainties on the exclusion limits

We turn now to the discussion of the ATLAS and CMS limits in the light of the theoretical uncertainties that affect the Higgs production cross section and the decay branching ratios. These uncertainties have been discussed in detail in Ref. [12] and can be summarized as follows, starting with the $gg \to A$ and $b\bar{b} \to A$ production cross sections.

– The uncertainty from the missing higher orders in perturbation theory is estimated by varying the renormalization and factorization scales in the domains $\mu_0/\kappa \le \mu_R, \mu_F \le \kappa\mu_0$ around the central scales μ_0, with the additional restriction $1/\kappa \le \mu_R/\mu_F \le \kappa$ imposed. While we choose $\kappa = 2$ for the $gg \to A$ process, the value $\kappa = 3$ is adopted for $b\bar{b} \to A$.

– In $gg \to A$, an additional uncertainty is due to the choice of the scheme for the renormalization of the b–quark mass which is estimated by taking the difference between the results obtained in the on–shell mass and $\overline{\rm MS}$ schemes and allowing for both signs. In $b\bar{b} \to A$, the inclusion of this effect is similar to increasing the domain of scale variation from $\kappa = 2$ to $\kappa = 3$.

– The combined uncertainty from the PDFs and the coupling α_s are estimated within the MSTW scheme [17] by considering the PDF$+\Delta^{\rm exp}\alpha_s$ uncertainty at the 90% CL to which we add in quadrature the impact of a theoretical error on α_s as estimated by MSTW, $\Delta^{\rm th}\alpha_s \approx 0.002$ at NNLO. We also add in quadrature a small uncertainty due to the b–quark pole mass value, $M_b = 4.75 \pm 0.25$ GeV, in the b–quark and gluon densities.

– Finally, there is the parametric uncertainty from the b–quark mass, $\overline{m}_b(\overline{m}_b) = 4.19^{+0.18}_{-0.06}$ GeV [24] and, for $b\bar{b} \to A$, from $\alpha_s(M_Z^2) = 0.1171 \pm 0.0014$ at NNLO [17].

The uncertainties are combined as follows (see Refs. [12,23] for the argumentation): the PDF$+\Delta\alpha_s+\Delta m_b$ uncertainty are evaluated on the minimal and maximal values of the cross sections with respect to scale and scheme variation[6]; to this, we add linearly the parametric uncertainty on $\overline{m}_b$ which will drop anyway in the final result (see below).

The results for the individual and total uncertainties on the production cross sections at

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GeV) which have been excluded by the recent ATLAS and CMS analyses [22]. The small $\alpha_{\rm eff}$, which leads to $\tilde{m}_g = 500$ GeV and $\tilde{m}_q = 800$ GeV is probably also excluded, in particular if the various ATLAS and CMS analyses are combined. This latter scenario leads to a huge (and probably rather problematic) Δ_b value but the effect on the cross section times branching ratio is again less than 10% for $\tan\beta \lesssim 30$.

[6] This procedure gives results that are similar to those obtained with a linear addition of the scale+scheme and PDF$+\Delta\alpha_s+\Delta m_b$ uncertainties as advocated in, for instance, Ref. [13]. Note that in this reference, from which the ATLAS and CMS estimate of the uncertainty is borrowed, only the scale and PDF$+\alpha_s^{\rm exp}$ uncertainties are considered leading to a smaller total uncertainty than the one we assume in our study.

the lHC are shown in Fig. 2 (left and central) for the $gg \to A$ and $b\bar{b} \to A$ processes as a function of M_A. One can see that a total uncertainty of $\approx +60\%, -40\%$ for $\sigma(gg \to \Phi)$ and $\approx +50\%, -30\%$ for $\sigma(b\bar{b} \to \Phi)$ are obtained in the 100–300 GeV Higgs mass range.

Finally, the total uncertainty on the cross section times branching ratio $\sigma(pp \to \tau^+\tau^-)$ is obtained by adding the total uncertainties on the two production cross sections[7] and the uncertainties on the branching fraction in Higgs decays into $\tau^+\tau^-$ pairs. The latter is simply affected by the parametric uncertainties on the input b–quark mass and the value of α_s; one finds an uncertainty of $\approx +4\%, -9\%$ on $\mathrm{BR}(\Phi \to \tau^+\tau^-)$ at the 1σ level over the entire relevant Higgs mass range, $M_A = 100$–300 GeV. When included, the latter uncertainties will cancel the parametric uncertainties in the cross section generating a slightly smaller total uncertainty in the cross section times branching ratio compared to the cross section alone. This is exemplified in the right hand–side of Fig. 2 where both total uncertainties are displayed.
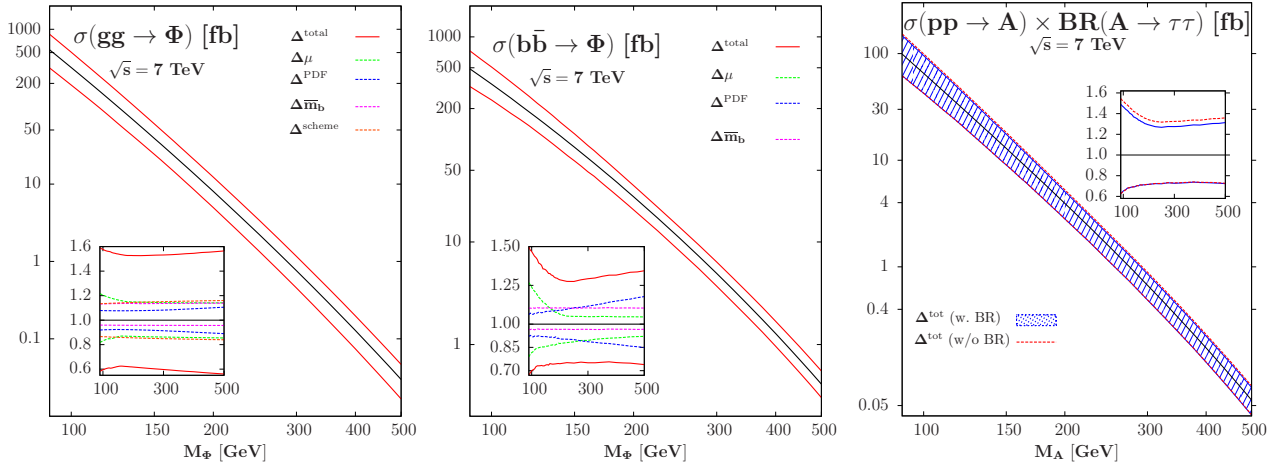

Figure 2: The cross sections $\sigma_{gg \to A}^{\mathrm{NLO}}$ (left) and $\sigma_{b\bar{b} \to A}^{\mathrm{NNLO}}$ (center) at lHC energies as a function of M_A when using the MSTW PDFs and unit $Ab\bar{b}$ couplings and the various individual and total uncertainties. The combined $\sigma(pp \to A) \times \mathrm{BR}(A \to \tau^+\tau^-)$ total theoretical uncertainties with and without the branching ratio is shown in the right panel. In the inserts, shown are the various theoretical uncertainties when the rates are normalized to the central values.

To illustrate the impact of these theoretical uncertainties on the MSSM $[M_A, \tan\beta]$ parameter space that has been probed at the lHC in the $pp \to \Phi \to \tau^+\tau^-$ channel, we consider the "observed" values of the cross section times branching ratio that have been given by the CMS collaboration[8] for the various values of M_A [2] and turn them into exclusion limits in this plane by simply rescaling $\sigma(gg + b\bar{b} \to A \to \tau\tau)$ by a factor $2 \times \tan^2\beta$.

This is shown in Fig. 3 where the contour of the cross section times branching ratio in this plane is displayed, together with the contours when the uncertainties are included. However, rather than applying the limits on the central $\sigma \times \mathrm{BR}$ rate (as the CMS and also ATLAS

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[7]We simply add all uncertainties linearly, in contrast to Ref. [13] in which the PDF uncertainties in gg and $b\bar{b} \to A$ are added in quadrature, with the total PDF+α_s uncertainty added linearly to the scale uncertainty.

[8]Unfortunately, the ATLAS collaboration has not given this important information in its note [1]. But as the ATLAS exclusion limits are similar to those obtained by the CMS collaboration, the final results once the theory uncertainties have been included should be the same.

collaborations do), we apply them on the minimal one when the theory uncertainty is included. Indeed, since the latter uncertainty is of theoretical nature, we will consider that it has a flat prior and, hence, the minimal cross section times branching ratio value is as respectable and likely as the central value. In this case, one observes that only values $\tan\beta \gtrsim 28$ are excluded for a Higgs mass $M_\Phi \approx 130$ GeV, compared to $\tan\beta \gtrsim 23$ if the central prediction is considered as in the CMS analysis. Hence, the inclusion of the theory uncertainties should lead to a slight reduction of the excluded $[M_A, \tan\beta]$ parameter space.
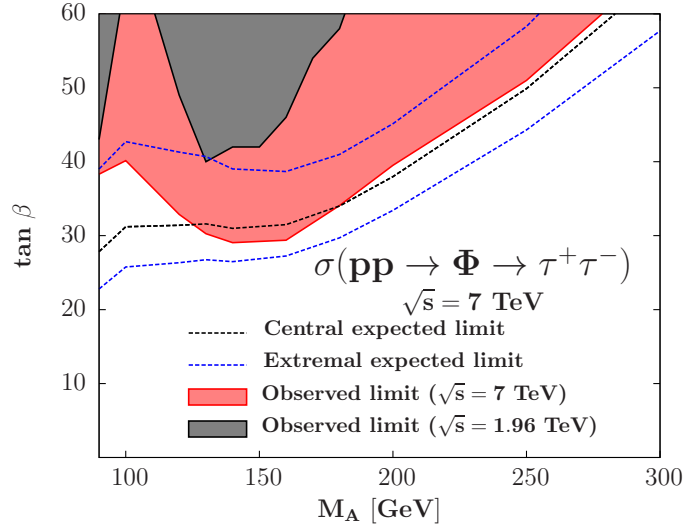

Figure 3: Contours for the expected $\sigma(pp \to \Phi \to \tau^+\tau^-)$ exclusion limits at the lHC in the $[M_A, \tan\beta]$ plane with the associated theory uncertainties, confronted to the 95% CL exclusion limits given by the CMS [2] and also CDF/D0 [5] collaborations when our procedure is applied.

4. Implications in the MSSM for higher luminosities

The exclusion limits on the $[\tan\beta, M_A]$ MSSM parameter space obtained by the ATLAS and CMS collaborations with only 36 pb^{-1} data are extremely strong as, for instance, values $\tan\beta \gtrsim 30$ are excluded in the low mass range for the pseudoscalar Higgs boson, $M_A = 90$–200 GeV. This has several consequences that we briefly summarize below.

First of all, if the luminosity is increased to the fb^{-1} level as is expected to be the case already at the end of this year, the values of $\tan\beta$ which can be probed will be significantly lower. Assuming that there will be no improvement in the analysis (which might be a little pessimistic as discussed later) and that the CMS sensitivity will simply scale as the square root of the integrated luminosity, the region of the $[\tan\beta, M_A]$ parameter space which can be excluded in the case where no signal is observed is displayed in Fig. 4 for several values of the accumulated luminosity. With 3 fb^{-1} data per experiment (or with 1.5 fb^{-1} when the ATLAS and CMS results are combined), values $\tan\beta \gtrsim 12$ could be excluded in the entire mass range $M_A \lesssim 200$ GeV; the exclusion reduces to $\tan\beta \gtrsim 20$ for the mass range $M_A \lesssim 300$ GeV.

These limits could be improved by considering four additional production channels.

i) The process $gb \to \Phi b \to b\bar{b}$ where the all final bottom quarks are detected: the production cross section $\sigma(bg \to b\Phi + g\bar{b} \to \Phi\bar{b})$ is one order of magnitude lower than that of
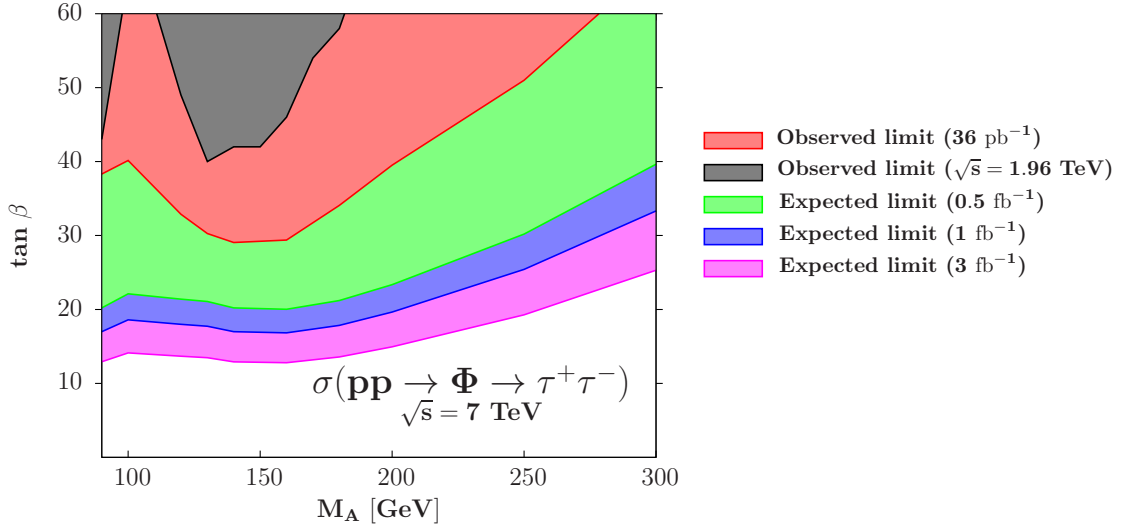
Figure 4: Contours for the "expected" $\sigma(pp \to \Phi \to \tau^+\tau^-)$ 95% CL exclusion limits at the lHC with $\sqrt{s} = 7$ TeV in the $[M_A, \tan\beta]$ plane for various integrated luminosities. The present limits from CMS and the Tevatron are also displayed.

the inclusive $gg + b\bar{b} \to \Phi$ process (the $bg \to b\Phi$ process is part of the NLO corrections to $b\bar{b} \to \Phi$ [9]) but this is compensated by the larger fraction $BR(\Phi \to b\bar{b}) \approx 90\%$ compared to $BR(\Phi \to \tau^+\tau^-) \approx 10\%$; the QCD background are much larger though[9].

ii) The process $pp \to \Phi \to \mu^+\mu^-$ for which the rate is simply given by $\sigma(pp \to \Phi \to \tau\tau)$ rescaled by $BR(\Phi \to \mu\mu)/BR(\Phi \to \tau\tau) = m_\mu^2/m_\tau^2 \approx 4 \times 10^{-3}$; the smallness of the rate[10] is partly compensated by the much cleaner $\mu\mu$ final state and the better resolution on the $\mu\mu$ invariant mass. The efficiency of the $pp \to \Phi \to \tau\tau$ signal is estimated by the CMS collaboration (see Table 1 of Ref. [2]) to be 4.5% when all τ decay channels are considered. This is only a factor 10 larger than the ratio $BR(\Phi \to \mu\mu)/BR(\Phi \to \tau\tau)$ (which is approximately equal to the efficiency in the $\tau \to e\mu$ channel). Thus the $\Phi \to \mu\mu$ decay channel might be useful. In particular, the small resolution that can achieved could allow to separate the three peaks of the almost degenerate h, H and A states in the intense coupling regime; see Ref. [19].

iii) The process $pp \to tbH^- \to tb\tau\nu$ which leads to a cross section that is also proportional to $\tan^2\beta$ (and which might also be useful for very low $\tan\beta$ values) but that is two orders of magnitude smaller than $\sigma(pp \to \Phi)$ for $M_A \approx 100$–300 GeV.

iv) Charged Higgs production from top quark decays, $pp \to t\bar{t}$ with $t \to H^+b \to \tau^+\nu b$, which has also been recently analyzed by the CMS collaboration [25]. With 36 pb^{-1} data, values of the branching ratio $BR(t \to H^+b) \gtrsim 25\%$ are excluded which means that only $\tan\beta$ values larger than 60 are probed for the time being[11].

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[9]We estimate the theoretical uncertainties on the rate $\sigma(bg \to Ab \to bb\bar{b})$ to be similar to that of the combined $gg + b\bar{b} \to \Phi$ process, that is ± 30–40%. Note, however, that here the parametric and supersymmetric corrections do not cancel in the cross section times branching ratio and have to be taken into account.

[10]Note that here, the parametric and supersymmetric corrections cancel out exactly in the cross section times branching ratio and we are left only with the scale/scheme and PDF+α_s uncertainties on the cross section that are exactly the same as those discussed previously.

[11]We note that in this case the theoretical uncertainties have not been estimated in Ref. [13] (contrary to the channel $pp \to tbH^- \to tb\tau\nu$ where an uncertainty of $\pm 30\%$ has been found). We have evaluated them with

Nevertheless, in the four cases, the small rates will allow only for a modest improvement over the $pp \to \Phi \to \tau\tau$ signal or exclusion limits. In fact, according to the (presumably by now outdated) projections of the ATLAS and CMS collaborations [29] at the full LHC with $\sqrt{s} = 14$ TeV and 30 fb^{-1} data, these processes are observable only for not too large values of M_A and relatively high values of $\tan\beta$ ($\tan\beta \gtrsim 20$) most of which are already excluded and the remaining part will be excluded if no signal is observed at the end of the present year. However, as is the case for the $pp \to \tau\tau$ channel, some (hopefully significant) improvement over these projections might be achieved.

5. Implications for the Standard Model Higgs boson

A very important consequence of the ATLAS and CMS $pp \to \tau\tau$ inclusive analyses is that they open the possibility of using this channel in the case of the Standard Model Higgs boson H. Indeed, in this case, the main production process is by far the $gg \to H$ channel which dominantly proceeds via a top quark loop with a small contribution of the bottom quark loop. The cross section for this process has been discussed in detail in Refs. [12,13] and, in the mass range $M_H = 115$–140 GeV, it is at the level of 10 to 20 pb. The branching ratio for the decay $H \to \tau^+\tau^-$ ranges from 8% at $M_H = 115$ GeV to 4% at $M_H = 140$ GeV. The cross section times branching ratio $\sigma(gg \to H \to \tau^+\tau^-)$ is thus rather substantial at low Higgs masses[12].

Using the numerical values of the SM Higgs cross sections and the decay branching ratio of Ref. [12] as well as the "median expected" and "observed" 95%CL limits obtained in the CMS analysis at $\sqrt{s} = 7$ TeV with 36 pb^{-1} data, we display in Fig. 5 the ratio of the observed and expected cross sections at the 95%CL normalised to the SM cross section $\sigma(gg \to H \to \tau^+\tau^-)$ as a function of the Higgs mass. One can see that with the small amount of data available today, we are a factor ≈ 50 to 60 above the expected rate in the SM in the mass range $M_H = 110$–140 GeV. However, when we compare this rate to the expected and observed rates (taken from a recent ATLAS analysis with 37.6 pb^{-1} data [27]) for the most important and promising channel for the SM Higgs boson in this mass range, $H \to \gamma\gamma$, one sees that the situation is not that bad. Indeed, the $gg \to H \to \tau\tau$ inclusive channel, which has not been considered neither by the ATLAS nor the CMS collaborations, is in fact rather powerful and competes rather well with the long celebrated $H \to \gamma\gamma$ detection channel, as it has a sensitivity that is only a factor of two smaller than the latter channel.

Thus, the $gg \to H \to \tau^+\tau^-$ channel could be also used to search for the SM Higgs in the very difficult mass range $M_H \approx 115$–130 GeV where only the $H \to \gamma\gamma$ channel was considered to be effective. The two channels could be combined to reach a better sensitivity. In addition, while little improvement should be expected in $H \to \gamma\gamma$ (for which the analyses have been tuned

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HATHOR [26] and, in the production channel $\sigma(pp \to t\bar{t})$ and for $m_t = 173.3 \pm 1.1$GeV, we find $\sigma(pp \to t\bar{t}) =$ 163 $^{+2.5\%}_{-5.6\%}$ (factor 2 from central m$_t$ scale) $^{+10.4\%}_{-10.1\%}$ (PDF$+\Delta^{\mathrm{exp+th}}\alpha_s$@90%CL) $\pm 3.3\%$ (Δm_t) pb, which leads using the procedure of Ref. [23] to a total uncertainty of $\Delta\sigma/\sigma = ^{+16\%}_{-19\%}$, i.e three times larger than the one assumed in the CMS analysis. To that, one should add the uncertainty on the branching ratio BR($t \to H^+ b$) for which the parametric one (from the input $\overline{m}_b$ and α_s values) is about $+10\%, -4\%$ [12].

[12]The cross section in the SM is comparable to that of $A + H(h)$ production in the MSSM with values $\tan\beta \approx 4$ (and not $\tan\beta = 1$!), a consequence of the dominance of the top–quark loop (in the SM) compared to bottom–quark loop (as is in general the case in the MSSM) in the gg fusion process.
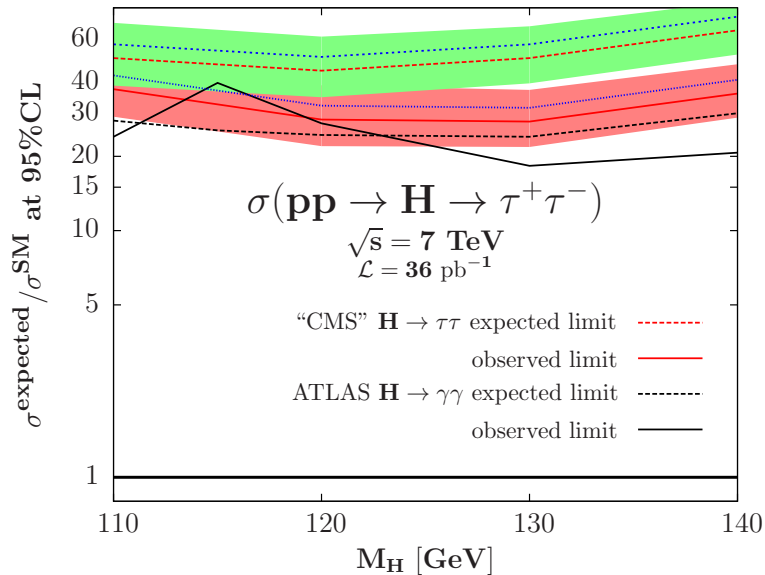
Figure 5: The median expected and observed cross sections at 95% CL for the production of the SM Higgs boson in the channels $gg \to H \to \tau\tau$ (blue lines) and $pp \to H \to \tau^+\tau^- + X$ (red lines captioned) from an extrapolation of the CMS analysis with 36 pb^{-1} data [2] normalised to the SM cross section. It is compared to the case of $H \to \gamma\gamma$ as recently analyzed by the ATLAS collaboration [27] with 37.6 pb^{-1} data.

and optimised for more than twenty years now), a better sensitivity could be achieved in the $H \to \tau^+\tau^-$ channel. Indeed, on the one hand, a possible improvement might come from the experimental side: novel and better mass reconstruction techniques of the $\tau\tau$ resonance can be used[13], splitting of the analysis into jet multiplicities as done for instance for the channel $H \to WW \to \ell\ell\nu\nu$, inclusion of additional topologies such as same sign $\ell = e, \mu$ final states, etc... On the other hand, one can render the $H \to \tau\tau$ channel more effective by simply including the contribution of the other Higgs production mechanisms such as vector boson fusion[14] and associated production with a W and Z bosons, which will increase the cross section for the inclusive $pp \to \tau\tau + X$ production mechanism by 15 to 20%. This is exemplified in Fig. 5 where the sensitivity is shown when the additional contributions of these processes are (naively, i.e. without making use of the specific cuts for vector boson fusion which will significantly increase the sensitivity) included in the cross section for the inclusive $pp \to H \to \tau^+\tau^- + X$ signal.

Hence, the $pp \to \text{Higgs} \to \tau^+\tau^-$ inclusive channel turns out to be a very interesting and potentially very competitive Higgs detection channel also in the Standard Model and it should be considered with a higher priority by the ATLAS and CMS collaborations.

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[13]In Ref. [30], a new mass technique for reconstructing resonances decaying into τ lepton pairs has been proposed and it is claimed that it allows for a major improvement in the search for the Higgs→$\tau\tau$ signal.

[14]In fact, there are separate analyses of the vector boson fusion process with $H \to \tau\tau$ (first proposed in Ref. [28]) made by the ATLAS and CMS collaborations [29]. Because of the two additional forward jets, the sensitivity of this channel (the only one involving τ leptons that has been considered in the SM so far) is much larger than its contribution ($\approx 10\%$) to the total $pp \to H \to \tau\tau + X$ inclusive rate indicates.

6. Conclusions

We have discussed the implications of the recent analyses performed by the ATLAS and CMS collaborations in the $pp \to \tau^+\tau^-$ search for the MSSM neutral Higgs bosons with 36 pb^{-1} data. The results lead to very strong constraints on the $[\tan\beta, M_A]$ MSSM parameter space. We have shown that these constraints are essentially model independent (for the values of M_A and $\tan\beta$ that are being probed so far) and slightly less effective when the theoretical uncertainties in the predictions for the Higgs cross sections and branching ratios are properly included. If a Higgs signal is still absent with a few inverse femtobarn data, these limits can be significantly improved and values $\tan\beta \lesssim 10$ can be excluded for not too heavy neutral Higgs bosons. At this stage, many channels such as $pp \to \Phi \to \mu^+\mu^-$, $pp \to btH^- \to bt\tau\nu$, $gb \to \Phi b \to 3b$ and $t \to H^+b$ will not be viable anymore even at the design energy and luminosity of the LHC.

The most important remark that we make in this note is that the inclusive $pp \to$ Higgs $\to \tau\tau$ process is also a very promising channel in the search for the Standard Model Higgs boson. Indeed, this channel has a sensitivity that is only a factor of two smaller than the expected sensitivity of the main $pp \to H \to \gamma\gamma$ channel. While little improvement is expected in the later channel, there are ways to significantly enhance the sensitivity of the $pp \to H \to \tau\tau$ signal and render it a very powerful discovery channel for the SM Higgs boson in the difficult $M_H = 115$–130 GeV mass range. We thus urge our experimental colleagues from the ATLAS and CMS collaborations to very seriously consider this additional and promising possibility.

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